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비트 패턴 자기기록 채널을 위한 2차원 변조부호

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A Two-Dimensional Code for Bit Patterned Magnetic Recording Channel

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요 약

본 논문에서는 비트 패턴드 자기기록 저장장치 채널을 위한 2차원 변조부호를 제안한다. 패턴드 미디어 기록장치는 하나의 자성점에 한 비트의 정보를 저장한다. 정보저장 기록 밀도를 높이기 위하여 인접한 트랙 사이의 간격을 아주 좁게 만들기 때문에 인접한 트랙간 간섭(intertrack interference, ITI)과 인접한 심볼간 간섭(intersymbol interference, ISI)이 문제가 된다. 따라서 한 비트 신호의 진폭은 2차원 간섭에 의해 변형된다. 같은 값으로 둘러싸인 비트의 신호가, 특히 어느 한 비트의 값이 둘러싸인 여덟 비트의 값과 동일한 경우 영향을 받는다. 제안된 변조부호 방법은 기존의 변조부호보다 좋은 부호율을 가지면서 위와 같은 최악의 경우가 발생하지 않도록 하므로써 패턴드 미디어의 기록 성능을 향상시키도록 한다.

Key Words : Bit patterned magnetic recording, Two-dimensional intersymbol interfernece, Two-dimensional modulation code

ABSTRACT

In this paper, a two-dimensional (2-D) channel code for magnetic patterned media is proposed. Patterned media records an information bit on a magnetized dot. Since the space between adjacent tracks is narrow in order to increase the storage density, inter-track interference (ITI) and inter-symbol interference (ISI) can be problems. The amplitude of a bit signal can be corrupted by the 2-D ISI. The signal of the bit surrounded by the same value can be especially destructive, i.e. when its value is the same as the values of the eight surrounding bits. The proposed modulation coding scheme improves the decoding performance of patterned media by preventing this worst case and provides a better code rate than conventional channel codes.

Ⅰ. INTRODUCTION

As the recording densities of storage systems continue to increase, conventional magnetic storage systems have faced their limits. Those systems store information bits in magnetic grains [1,2]. To improve the recording density, the size of the grain should be reduced. However, this decreases its thermal stability.

Patterned media is one solution for this problem. Each information bit is stored on a magnetized dot called a magnetic island, and the spaces between islands are nonmagnetic regions. Therefore, bit patterned media prevents the

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super-paramagnetic limit. Also, the nonmagnetic region reduces transition noise and nonlinear bit shifts[3,4]. Bit patterned media consists of a two-dimensional (2-D) arrangement of islands, with each dot very close to its surrounding dots. As a result, inter-track interference (ITI) can be a problem for patterned media, in addition to inter-symbol interference (ISI) which is the main problem of conventional sequential recording storage. Therefore, this 2-D ISI has to be considered[5,6]. To mitigate the 2-D ISI for patterned media, many researchers have conducting research on the Viterbi algorithm, 2-D partial response equalizer, etc.[7-9]. Among those works, the 2-D channel codes have been designed to consider the patterned media by exploiting a probe recording scheme, unlike conventional magnetic recording[10,11].

With patterned media, the signal of a bit is very weak when the value of the bit has the same value as its surrounding eight bits. In other words, if the values of the data bits are all '0' bits or '1' bit in a 3-by-3 bit array, the amplitude of the center bit is much lower than its original amplitude [10]. Figure 1 illustrates the phenomenon. Unlike Fig. 1(a) and (b), Fig. 1(c) shows that the amplitude of the center bit which is surrounded by the same value is lowered. To prevent this problem (referred to as the worst case, in this paper), two-dimensional 7/9 modulation [10] and 5/6 modulation code [11] have been proposed. The 7/9 channel code places two redundant bits, which are one '1' bit and one '0' bit, on the predefined position in every 3-by-3 array. The 5/6 code also predefines the redundant bit positions. It places one parity bit with the value as opposed to adjacent bits among every 3-by-2 bit array. In [10], [11], the codes show better performance than no coding scheme. In this work, we propose a 2-D modulation code preventing the situation that all nine bits in a 3-by-3 bit array have the same values. The proposed code has a higher code rate than the previous two codes.

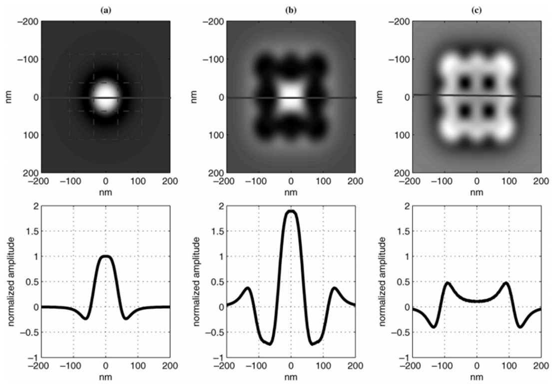

Fig. 1. Read signals of (a) single bit, (b) "one" bit surrounded by eight "zero" bits, and (c) nine "one" bits [10].

c_0	c_1
c_2	c_3
c_4	c_5
c_6	c_7

Fig. 2. Position of each codeword bit in a codeword.

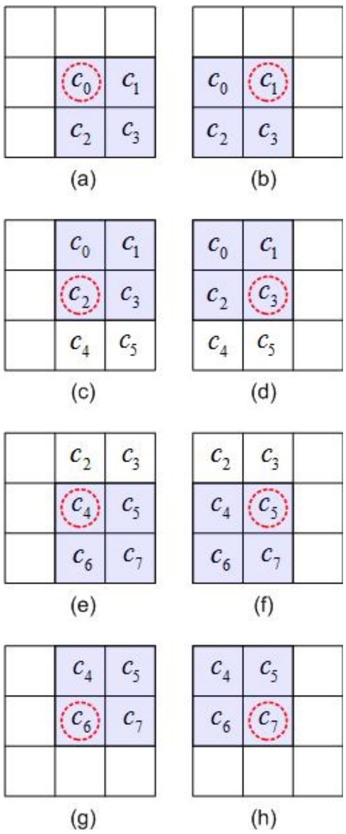

Fig. 3. All possible 2-by-2 bit patterns of the proposed codeword in a 3-by-3 bit array.

Ⅱ. PRPOSED 7/8 MODULATION CODE

The codewords consist of a 4-by-2 bit array ($c_i, i=0, \cdots, 7$). The position of each codeword bit c_i should be the same as shown in Fig. 2. In this way, the 2-by-2 bit array patterns in a codeword are (c_0, c_1, c_2, c_3), (c_2, c_3, c_4, c_5), and (c_4, c_5, c_6, c_7), and every neighboring four bits (2-by-2 bit array) in the codeword (4-by-2 bit array) are always included in every 3-by-3 array and compose the fractions of codewords after modulation coding. This is illustrated in Fig. 3. The dotted circle bits in Fig. 3(a) through 3(h) represent the bit influenced by the surrounding eight bits. If the nine bits (a dotted circle bit and the surrounding eight bits) are all the same, this is the worst case.

Assuming a codeword assignment such that $c_i = d_i$ for $i=0, 1, \cdots, 6$ (d_i: source data) and $c_7 = 0$ for a parity bit, the worst case does not happen if the shaded bit parts are not the same. In other words, four bits do not have the same value of 0 or 1. Thus, for the cases of (a), (b), (c) and (d) in Fig. 3, the worst case does not happen if the four input bits (d_0, d_1, d_2, d_3) do not have the same value. But, if they have the same value, the corresponding codewords have to be created in a different way. There are sixteen input source data patterns in order for the four input bits (d_0, d_1, d_2, d_3) to have the same value, and they are (0, 0, 0, 0, 0, 0, 0), (0, 0, 0, 0, 0, 0, 1), $\cdots$, (0, 0, 0, 0, 1, 1, 1), (1, 1, 1, 1, 0, 0, 0), (1, 1, 1, 1, 0, 0, 1), $\cdots$, and (1, 1, 1, 1, 1, 1, 1). For the cases of (e), (f), (g) and (h) in Fig. 3, the worst case may occur only if the three input bits (d_4, d_5, d_6) are equal to 0, because the parity bit c_7 is set equal to 0. In this case, the worst case can be prevented if the parity bit is set as 1 instead of 0, because the neighboring four bit pattern becomes (c_4, c_5, c_6, c_7)=(0, 0, 0, 1). Therefore, the proposed 7/8 modulation coding scheme prevents the worst case, as the neighboring four-bit patterns (c_0, c_1, c_2, c_3) and (c_4, c_5, c_6, c_7) in a codeword cannot have the same value of 1 or 0.

Figure 4 is the encoding algorithm of the proposed modulation code. The encoder checks the source data (d_i, $i=0, \cdots, 6$). If (d_0, d_1, d_2, d_3) are identical, the corresponding output codeword is defined by the logic system in Fig. 5(a), and the output codeword is $(d_4, d_0, d_5, \sim d_5, 0, d_6, 1, 1)$, where '$\sim d_5$' means the opposite value of the bit d_5. Otherwise, the encoding system checks (d_4, d_5, d_6). If (d_4, d_5, d_6) are all equal to 0, the encoder sets the codeword bits to $c_i = d_i$ for $i=0, 1, \cdots, 6$ and $c_7 = 1$. For all other cases, the codeword is set to $c_i = d_i$ for $i=0, 1, \cdots, 6$ and $c_7 = 0$.

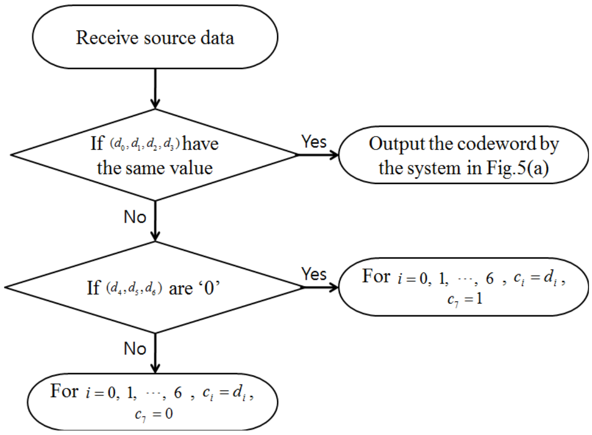

Fig. 4. Encoding procedure.

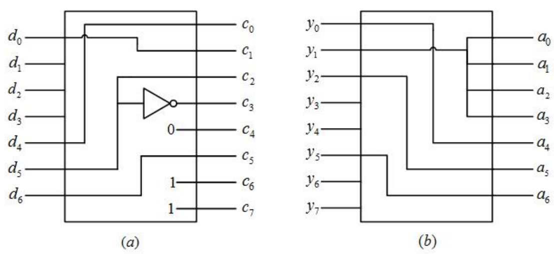

Fig. 5. The logic systems for (a) encoding and (b) decoding process when $d_0 = d_1 = d_2 = d_3$.

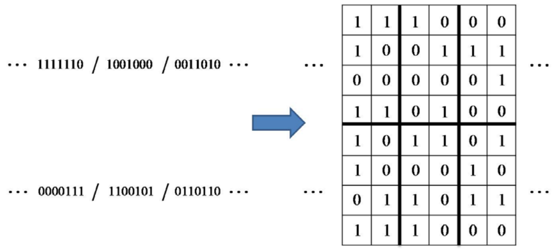

Fig. 6. Example of the proposed coding scheme.

When decoding the received codeword (y_i, $i=0, \cdots, 7$), the decoder checks the last two bits y_6 and y_7. If both symbols are equal to 1, the decoder restores the source data (a_i, $i=0, \cdots, 6$) by using the system in Fig. 5(b). Since c_6 and c_7 are equal to 1 in Fig. 5(a), the decoder can distinguish if the received codeword is defined by the logic system in Fig. 5(a) (i.e., (d_0, d_1, d_2, d_3) are identical), those codewords can be restored by the decoding logic as in Fig. 5(b). Otherwise, the decoder restores the source data as $a_i = y_i$ for $i=0, 1, \cdots, 6$.

Figure 6 illustrates an encoding example when the source data are (1, 1, 1, 1, 1, 1, 0), (1, 0 ,0, 1, 0, 0, 0) and (0, 0, 1, 1, 0, 1, 0) in the upper row, and (0, 0, 0, 0, 1, 1, 1), (1, 1, 0, 0, 1, 0, 1) and (0, 1, 1, 0, 1, 1, 0) in the lower row. The decoder restores the source data from the received codewords (1, 1, 1, 0, 0, 0, 1, 1), (1, 0, 0, 1, 0, 0, 0, 1), (0, 0, 1, 1, 0, 1, 0, 0), (1, 0, 1, 0, 0, 1, 1, 1), (1, 1, 0, 0, 1, 0, 1, 0) and (0, 1, 1, 0, 1, 1, 0, 0) by checking the seventh and eighth bits, first. If they are 1, the decoder outputs the source data by the logic in Fig. 5(b). Otherwise, it outputs the first seven bits as the restored source data.

Ⅲ. CONCLUSION

The performance of bit patterned magnetic recording is degraded by 2D-ISI, especially, when the value of the center bit is the same as that of the surrounding eight bits. In this paper, a 2-D modulation code for magnetic patterned media recording was proposed. This prevents the situation in which all nine bits in a 3-by-3 array have the same value. The code rate of the proposed code is 7/8 which is higher than the previous conventional 7/9 and 5/6 channel codes in [10] and [11].

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